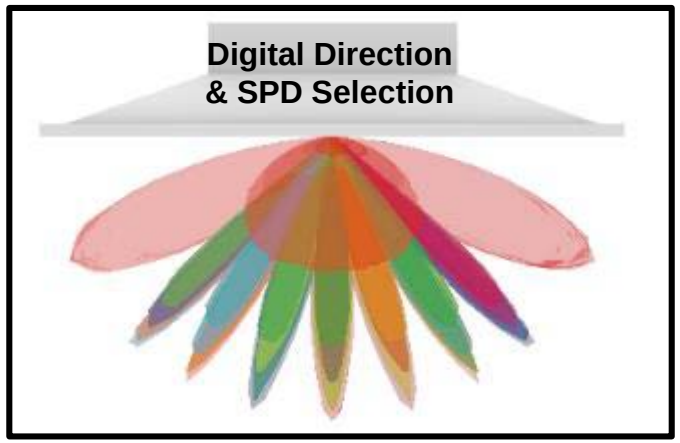
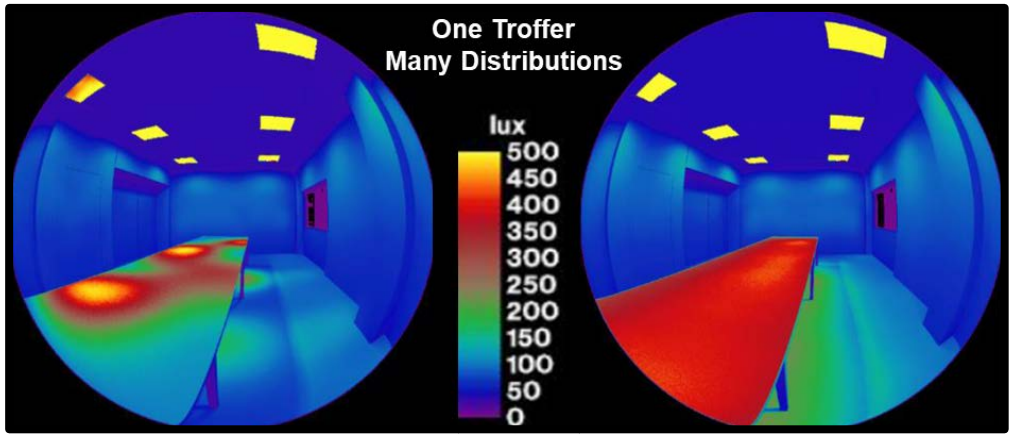
Spatially Adaptive Tunable Lighting Control System with Expanded Wellness and Energy Saving Benefits



+

=



Digitally Steerable Fixtures | Occupancy Driven controls | Optimized Illumination, Autonomous Control

Performing Organization(s): Rensselaer Polytechnic Institute, Lumileds, HKS
R. F. Karlicek, Jr. Professor, ECSE, Director, Center for Lighting Enabled Systems & Applications
karlir@rpi.edu

Project Summary

Timeline:

Start date: April 3, 2020

Planned end date: March 31, 2023

Key Milestones

1. Digital Troffer Design & Simulation: 03/2021
2. Working digital troffer installed: 12/2021
3. Simulate “Sculpting” for 3 installations: 12/2021
4. Full Installation energy/SPD testing: 02/2023

Budget:

Total Project $ to Date:

- DOE:$837,833
- Cost Share: $231,372

Total Project $:

- DOE: $2,046,888
- Cost Share: $715,706

Key Partners:

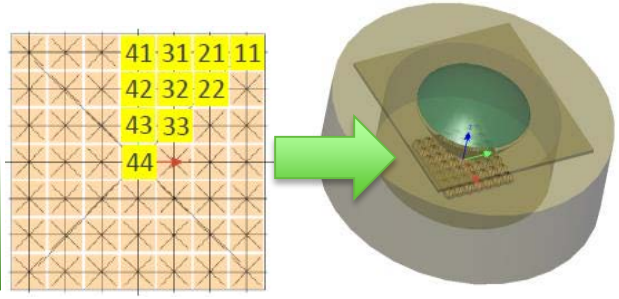
Rensselaer (LEAD)
Lumileds LLC
HKS, Inc.

Project Outcomes:

- Demonstrate troffer with digitally controlled variable beam patterns and color tuning
- Demonstrate autonomous lighting control that is occupant pose and position aware
- Quantify light application efficiency improvements optimized for circadian performance

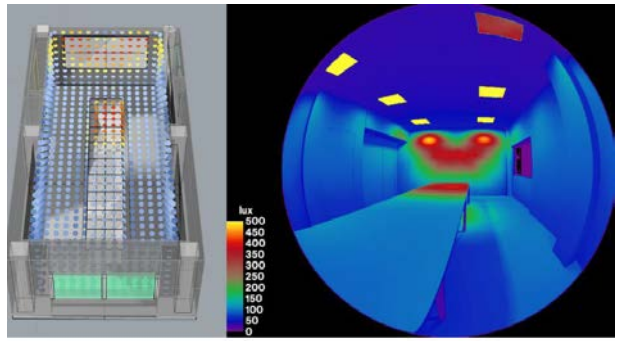
Team

Who	LUMILEDS	Rensselaer LESA CASE	HKS
Why	• Global Leader in LED die and module design • Experience in digital auto headlight beam control	• LESA – academic leadership in light field sensing and control • CASE – academic leadership in architectural design simulation	• Global Leader in architectural design and services • Extensive lighting design and light modeling capabilities
What	• Design and fabrication of multi-element, color tunable light module • Design and fabrication of light engine optical system	• Develop and demonstrate autonomous, occupant aware, dynamic lighting control • Design, install, commission and evaluate energy savings and human factors considerations	• Lighting simulation and algorithm development for multi-directional troffers • Simulation of energy and human factors performance in 3 different lighting installations



49 pixel LED die | Module with optics

Occupant pose/position and lighting control system



Lighting design optimization methods

Challenges

Problem (1): Modern fixtures are static, cannot control light placement

- Light goes to places where it is not needed, energy wasted
- Multiple fixture types installed, adding cost and control challenges

Problem (2): Lighting control systems are barely “occupant aware”

- Modern lighting controls are either primitive or too hard to use
- Energy savings from controls not realized because they too complex

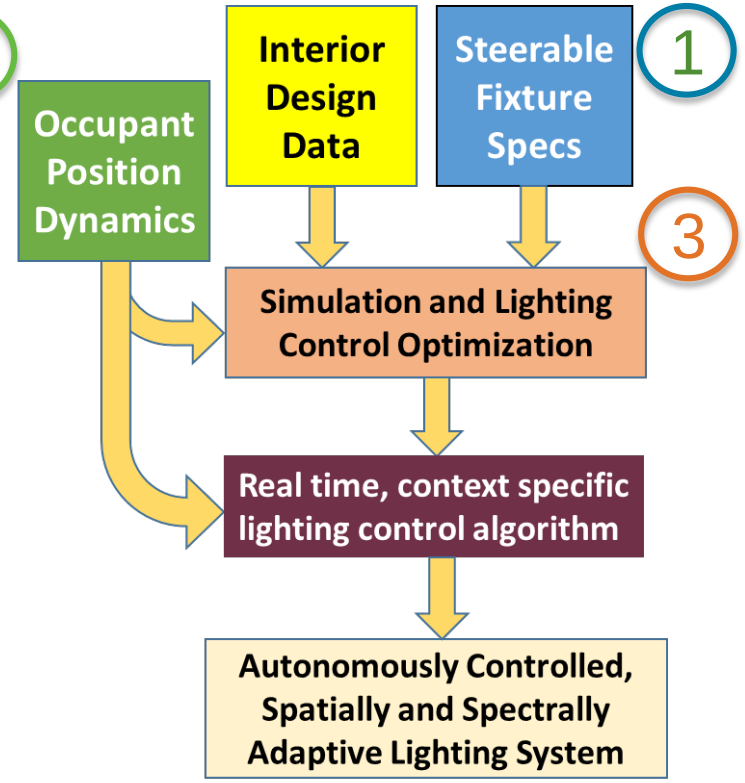
Problem (3): Color tunable lighting for human wellbeing is complex

- Tunable lighting uses more energy, control becomes even harder
- Different spectra for vertical (eye) and horizontal (table) illuminance

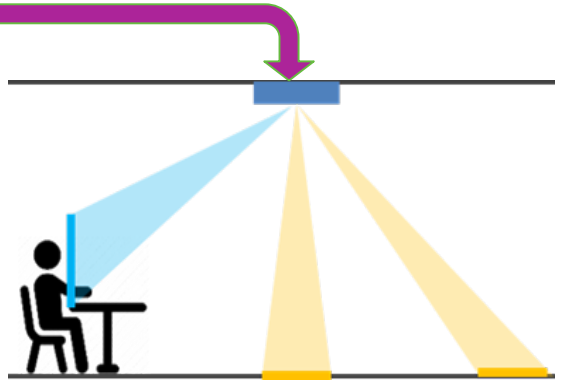
Approach

Accelerate the integration of:

1. Multi-element, beam steerable LED technology from automotive headlight research
2. Advanced occupancy sensing developments from building "occupant centric controls" research
3. Modern simulation, modeling and control platforms from VR rendering engine development and new lighting simulation tools



To **create a testbed** for validating the full **energy savings** and **human well being** potential of autonomous lighting systems that deliver the **right light where and when needed**



Key Challenges:

- Control complexity (many lighting profiles)
- Activity estimation for optimized illumination
- Human perception of dynamic lighting

Mitigation:

- Control algorithm optimization
- Match sensor data to fixed activity types
- Use digital twin (VR) to optimize design

Impact

A state of the art testbed integrating digital lighting control (spectrum and illuminance profiles) with occupant aware controls for studying energy and human performance

Impact Area	Goals	Comments
Lighting Energy Use Reduction	Up to 75%	• Depends on occupant density (impacts local dimming potential) • Depends on human factors research (light levels needed for circadian health)
Control Automation	Fully autonomous	• Overcomes issues of lighting control complexity • Occupancy sensing continues to improve, costs coming down fast
Building Automation	Integrate to HVAC, safety and security	• Precision localization from lighting control for reducing HVAC costs • Improved occupant "situational awareness" for a wide range of building systems like plug load control, security and emergency response • A key step to autonomous, sentient smart buildings through occupant awareness

Ultimate freedom in lighting design: light any surface from any angle with any illuminance and spectrum

Adaptive and digital lighting design: developing control algorithms instead of specifying fixtures

Lighting application efficiency: ideal light for any application = no light wasted

Building integration: streamlined supply chain, building construction/renovation, installation and commissioning

Marketing Pitch (Lumileds)

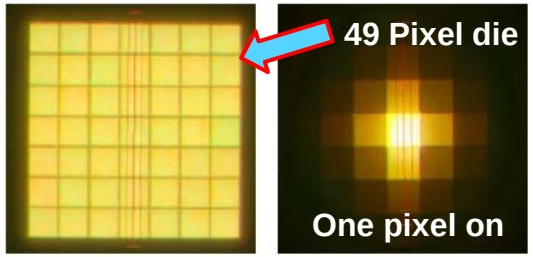
Progress **Project Stage:** Early-Middle (Q5 of 12Q program)

1 Light Engine

Projection section	
Beam angle FWHM	100°
Number of segments	49
Nominal flux per segment	500 lm

Light guide section	
Beam angle peak to peak	128°
Beam angle FWHM	152°
Number of segments	4
Nominal flux per segment	1400 lm

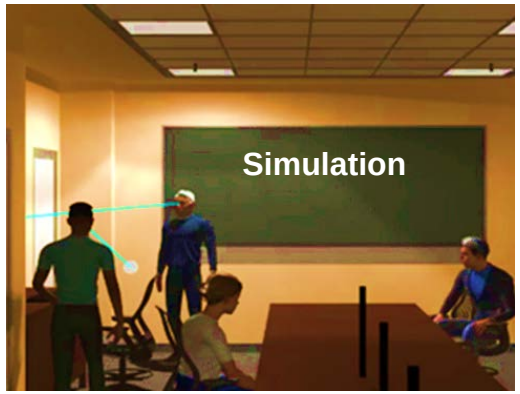
Spectrum (both sections)	
CCT range	2200-10000K
CRI (min 2700-6500K)	Ra>90, R9>50
Melanopic ratio (MDER)	0.35-1.12
Melanopic ratio (MEER)	0.38-1.24

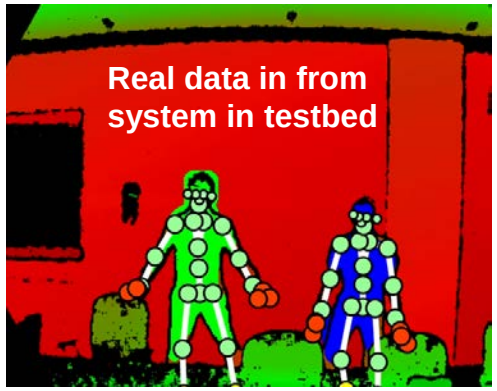


Progress on track, die/optics/driver fabrication & test in progress

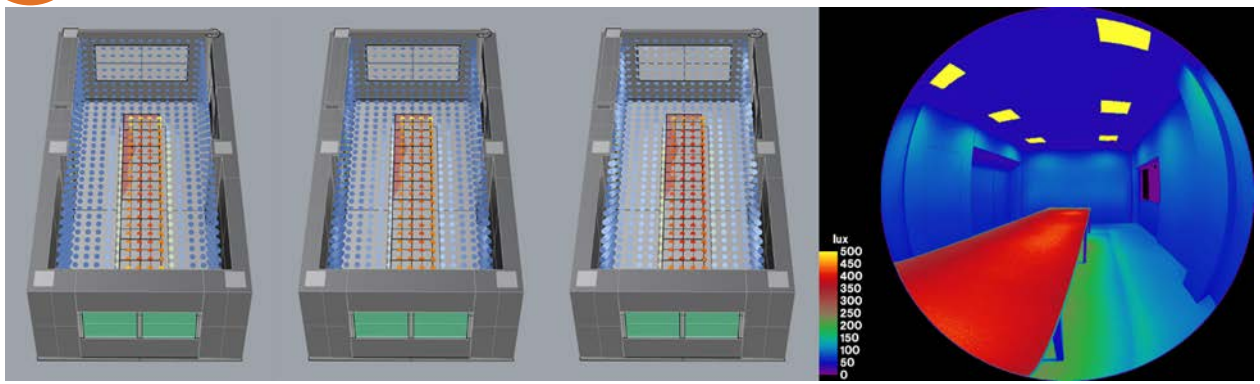
2 Occupant position dynamics (On Track)

- Position/gaze integrated
- Light steering linked to occupant position (Unity)
- Closed loop position/lighting development in progress





3 Illuminance Distribution Modeling/Programming



- 8 steerable troffers in room
- 53 beam profiles/troffer
- 424 (8x53) settings for room
- Algorithm optimizes settings

Good Progress On Track

$$\begin{bmatrix} E_1 \\ \vdots \\ E_m \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$$

Illuminance values

Illuminance at sample point 1..*m* due to pixel 1..*n*

Pixel output values

Additional Progress

- Luminaire housing
  - ~ 40% complete
  - Driver interface to light engine designed/tested
- Digital Twin Progress
  - ~ 80% complete
  - 1st person VR visualization in progress

  (tests look/feel test of light sculpting control algorithms)

Stakeholder Engagement **Project Stage:** Early-Middle (Q5 of 12Q program)

Key Stakeholders: Lighting, Building Controls, Architectural Design Firms

- Stakeholder engagement built into program (Lumileds, HKS are participants)
- Two presentations at 2021 Illumination Engineering Society (IES) Annual Meeting

Digitally Controlled, Beam Steerable and Tunable Lighting System with Occupancy Activity Estimation

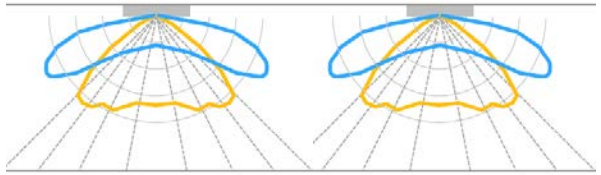
R. Karlicek, A. Tsamis, R. Radke, C. Varsami (Rensselaer)
W. Soer, F. Chiang (Lumileds)
H. May, E. Broberg, T. Logan (HKS)

Rensselaer

- Regular program updates with DOE SSL program at PNNL (broad stakeholder reach)
- Publications in technical and industry periodicals (planned)
- Broad LESA outreach to students, industry, conference presentations…

Remaining Project Work

Next Steps (remaining 25 months of program):



- Complete die fabrication and light engine design (Lumileds)
- Initiate luminaire design (housing, thermal management, power integration (RPI)
- Complete and test (simulation with VR) lighting algorithm operation
- Build/install 8 steerable luminaires in testbed (RPI)
- Complete testbed energy and human factors tests (RPI, HKS)

Longer Term (focus on cost down/commercial adoption):

- Continue promoting testbed capabilities (new funding, publications, conferences)
- Publish control algorithms for beam steerable lighting (open source)
- Explore position/pose sensing cost reduction (ongoing LESA Research on sensors)

Thank You

Performing Organization(s): Rensselaer Polytechnic Institute, Lumileds, HKS
R. F. Karlicek, Jr., Professor, ECSE, Director, Center for Lighting Enabled Systems & Applications
karlir@rpi.edu

REFERENCE SLIDES

Project Budget

Project Budget: *DOE share - $2,046,888 Cost share – $715,706 Total – $2,762,594*
Budget tracking below expected ramp, primarily due to pandemic related hiring and research issues at RPI. Lumileds and HKS budgets on track.

Variances: *Budget is below expected track – but spend rate increasing to with increased staffing at RPI to make up for pandemic related delays, no budget modifications expected*

Cost to Date: *DOE share - $837,833 Cost share – $231,372 Total – $1,069,205*

Additional Funding: *No other funding sources at present (other than mandatory cost share)*

Budget History					
FY 2020 (to 9/30/2020)		FY 2021 (10/1/2020 to 9/30/2021)		FY 2022 (10/1/2021 to 3/31/2023(End))	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
98,286	27,543	1,101,456	308,500	1,625,578	379,665

Project Plan and Schedule

- Program Start: April 2020
- Program on track, no missed milestones
- Two Go/NoGo Milestones: ♦
  - One met at end Q4
  - Other one on target for end Q7

- Program End: March 2023
- Going Forward:
  - Build and install luminaires in testbed
  - Complete/Test control with occupancy feedback
  - Complete energy savings and human factors tests

We are here

Task	Sub Task	Description	Budget Period 1 (Year 1)				Budget Period 2 (Year 2)				Budget Period 3 (Year 3)			
			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
1.0 Steerable/Tunable Fixture Development	1.1	System Design	Select reference light engine design (Elecrical/Optical) ♦											
	1.2	Build/Test Prototype Light Engine					Complete working prototype for initial light engine tests along with test results (efficiency, spectral and spatial tuning ranges)							
	1.3	Assemble light engines into luminaires, test/install							Operational steerable/tunable fixtures tested/installed in SCR testbed					
2.0 Digital Twin Development	2.1	Create integrated platform for digital twin viewing	Integrate TOF occupancy sensing visualization and training capabiltiy int VR platform with simulation testing for all three office designs											
	2.2	Develop adaptive lighting control concepts (interfaces to steerable luminaires)					Simulated occupancy sensing and dynamic beam steering based on three simulated occupancy scenarios for generating simulated sculpted light profiles ♦							
		Apply AR capabilities to SCR testbed								Optimize occupancy based light sculpting rules for SCT testbed using VR/AR tool with real occupant activity				
3.0 Light Utilization Efficiency Assessment	3.1	Testbed Photometry										Photometric validation of steering and spectral tuning capabilities		
	3.2	Evaluate Light Utilization Efficiency energy savings potential											Compare energy use for lighting profiles with real occupant testing	
4.0 Final Report	4.0	Final Program Report												Final Report